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(54) **HEAT DISSIPATION FOR A PHOTOVOLTAIC JUNCTION BOX**

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H02G 3/16 (2006.01)

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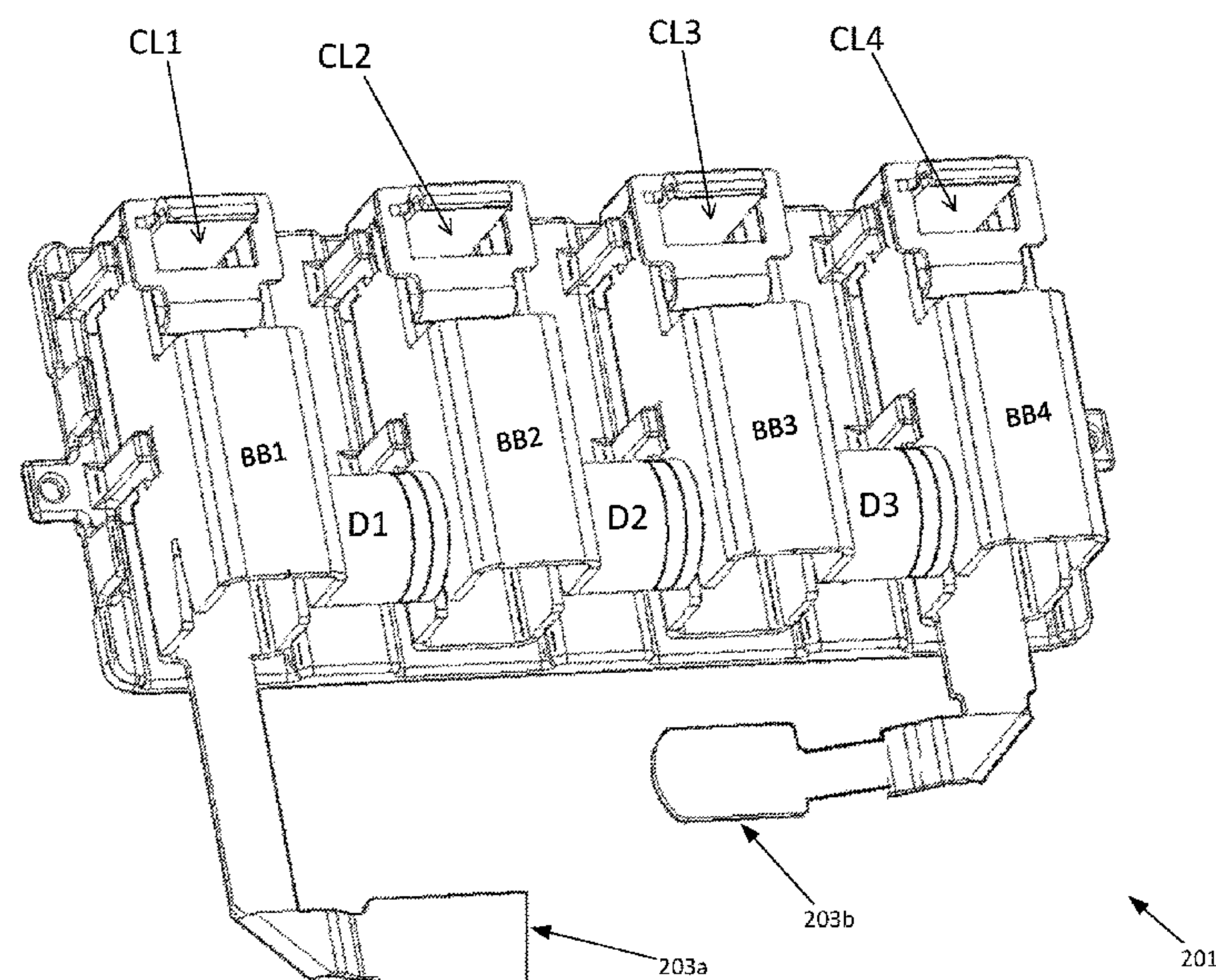
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(57) **ABSTRACT**

An apparatus of a junction box component housed in a junction box and designed to be coupled to a power generator. The junction box component may include one or more bypass mechanisms configured to bypass one or more substrings of the power generator in a case of malfunction or mismatch between the substring and the remainder of the power generators. The one or more bypass mechanisms may generate heat which may be transferred out of the junction box. The junction box component may be designed to conduct the heat towards the base of the junction box and/or the cover of the junction box. A heat dissipation mechanism may be mounted on the base and/or the cover. A bypass mechanism may bypass the entire power generator.

8 Claims, 13 Drawing Sheets



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Fig. 1

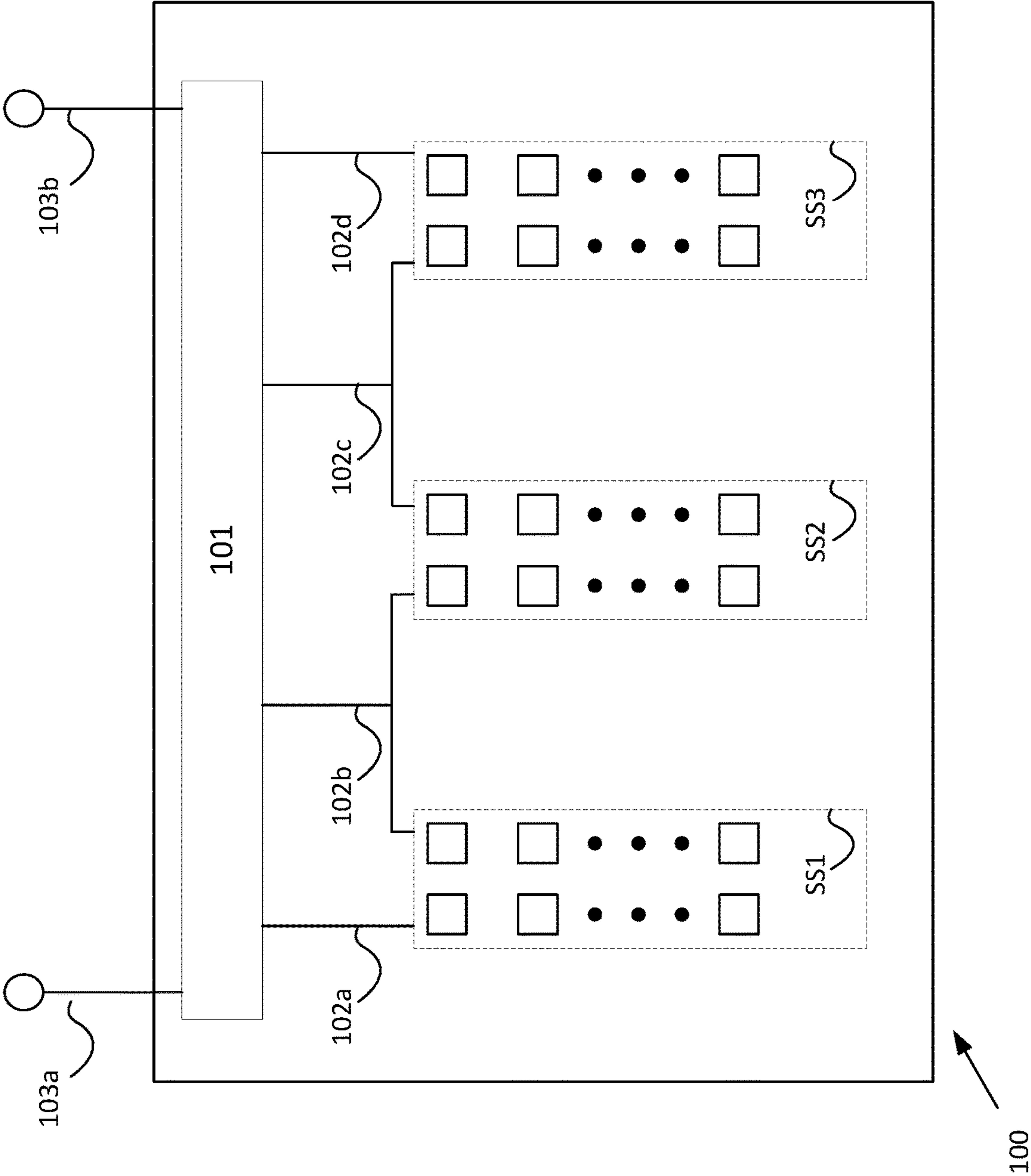


Fig. 2A

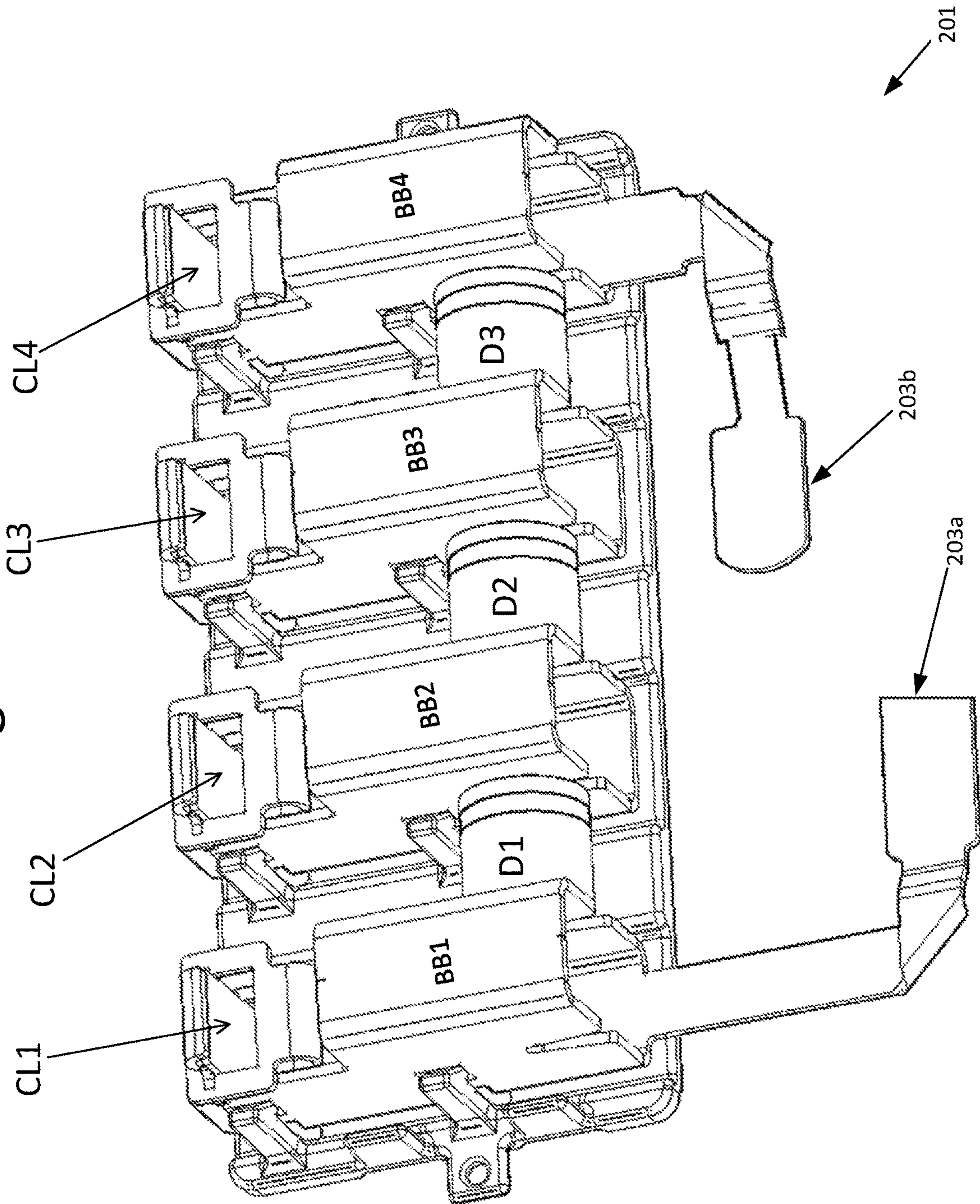
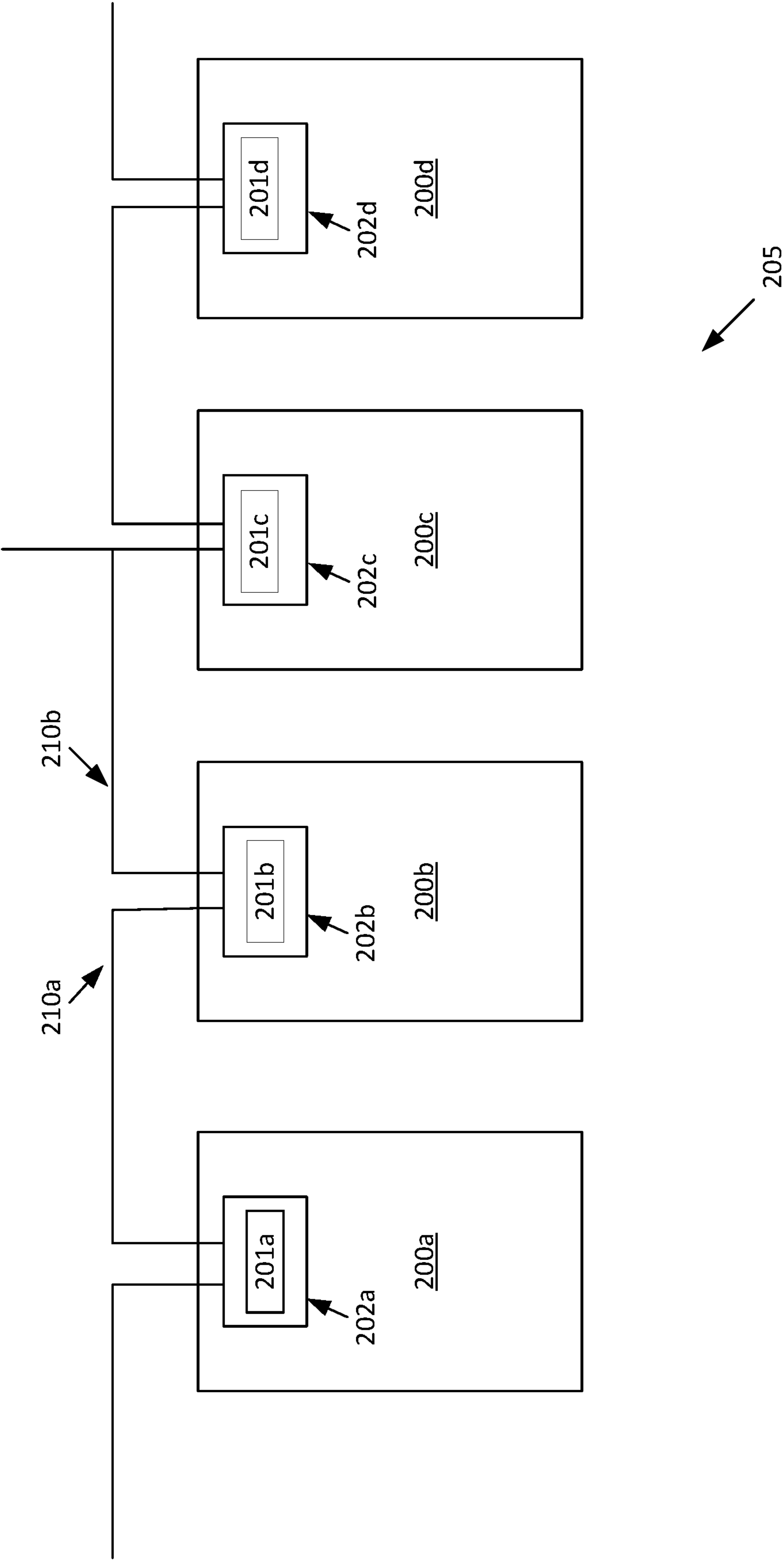
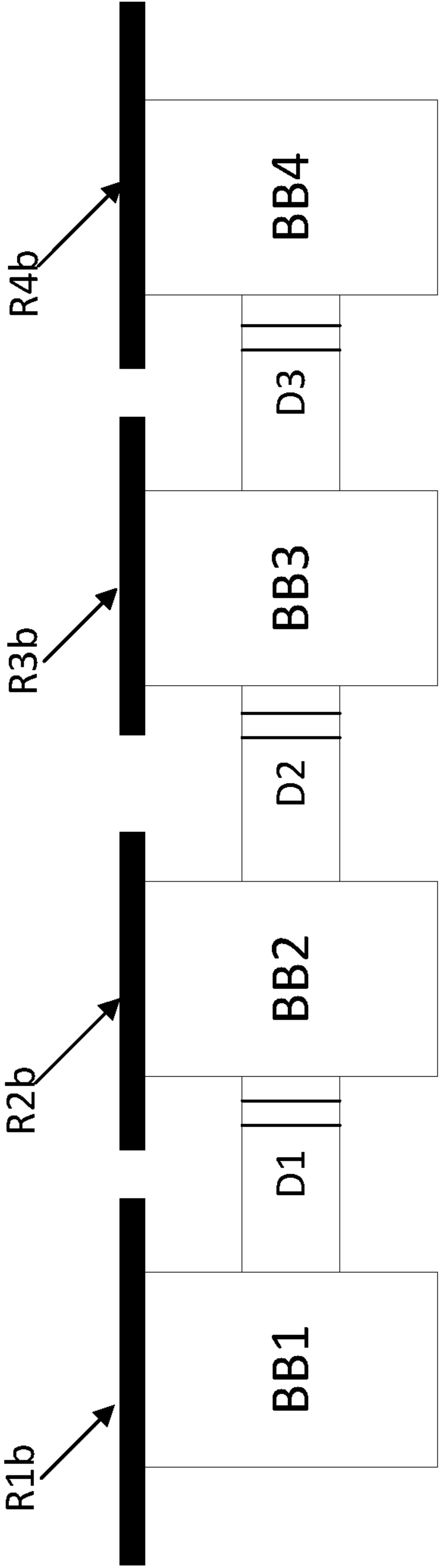
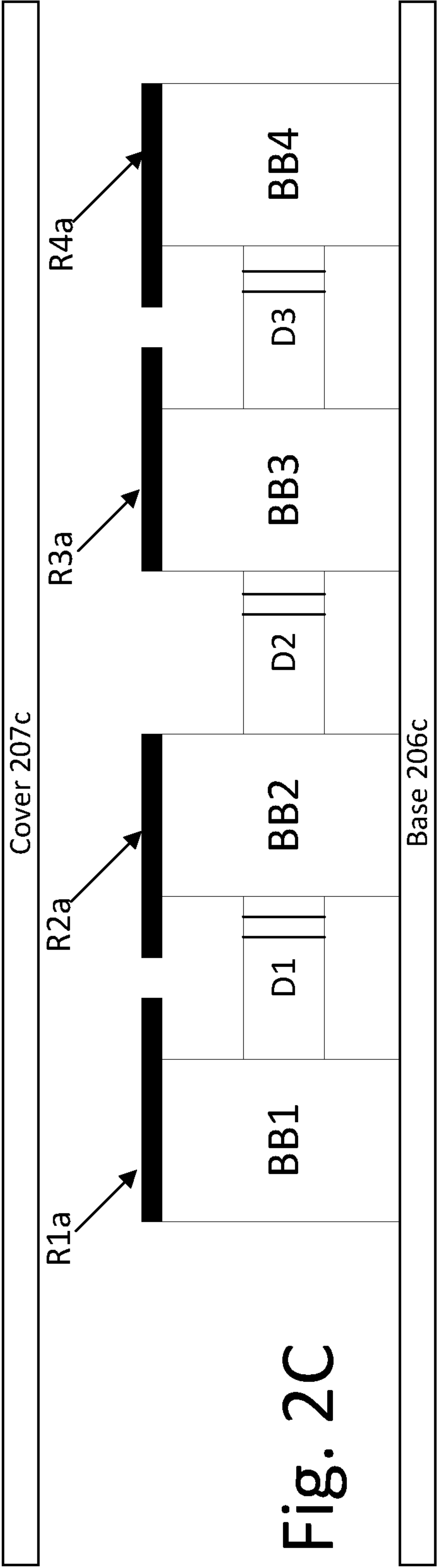


Fig. 2B





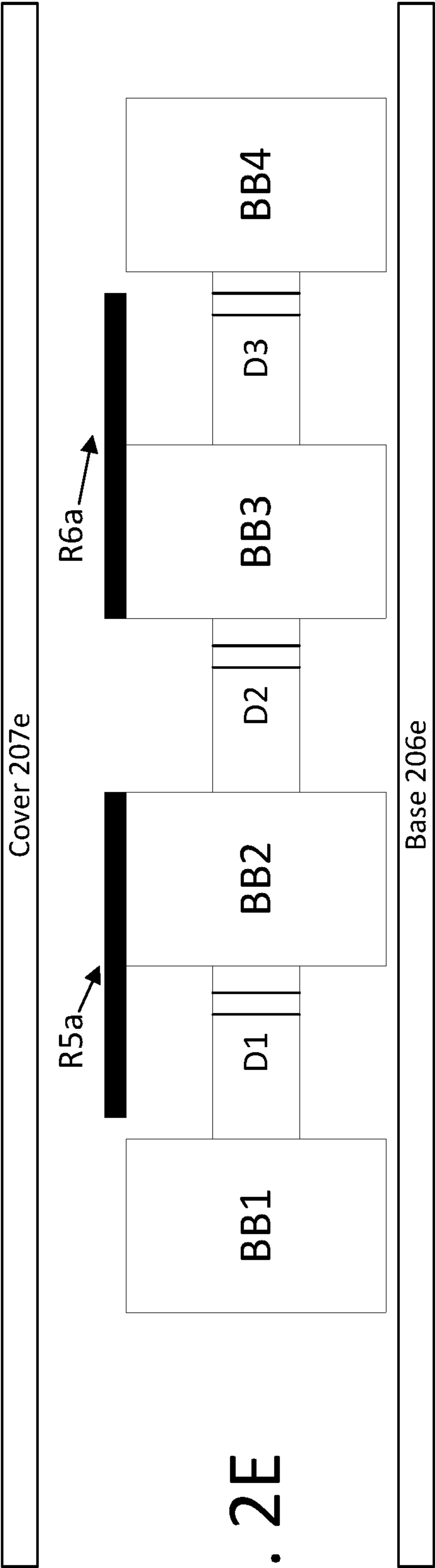


Fig. 2E

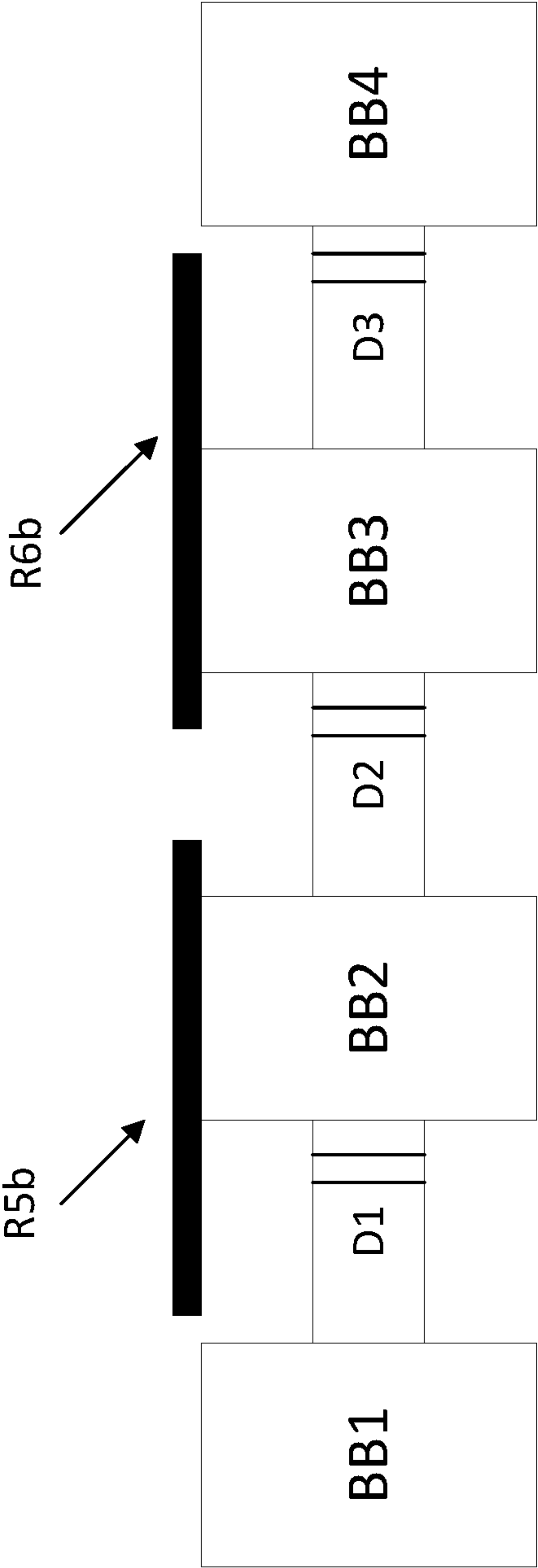
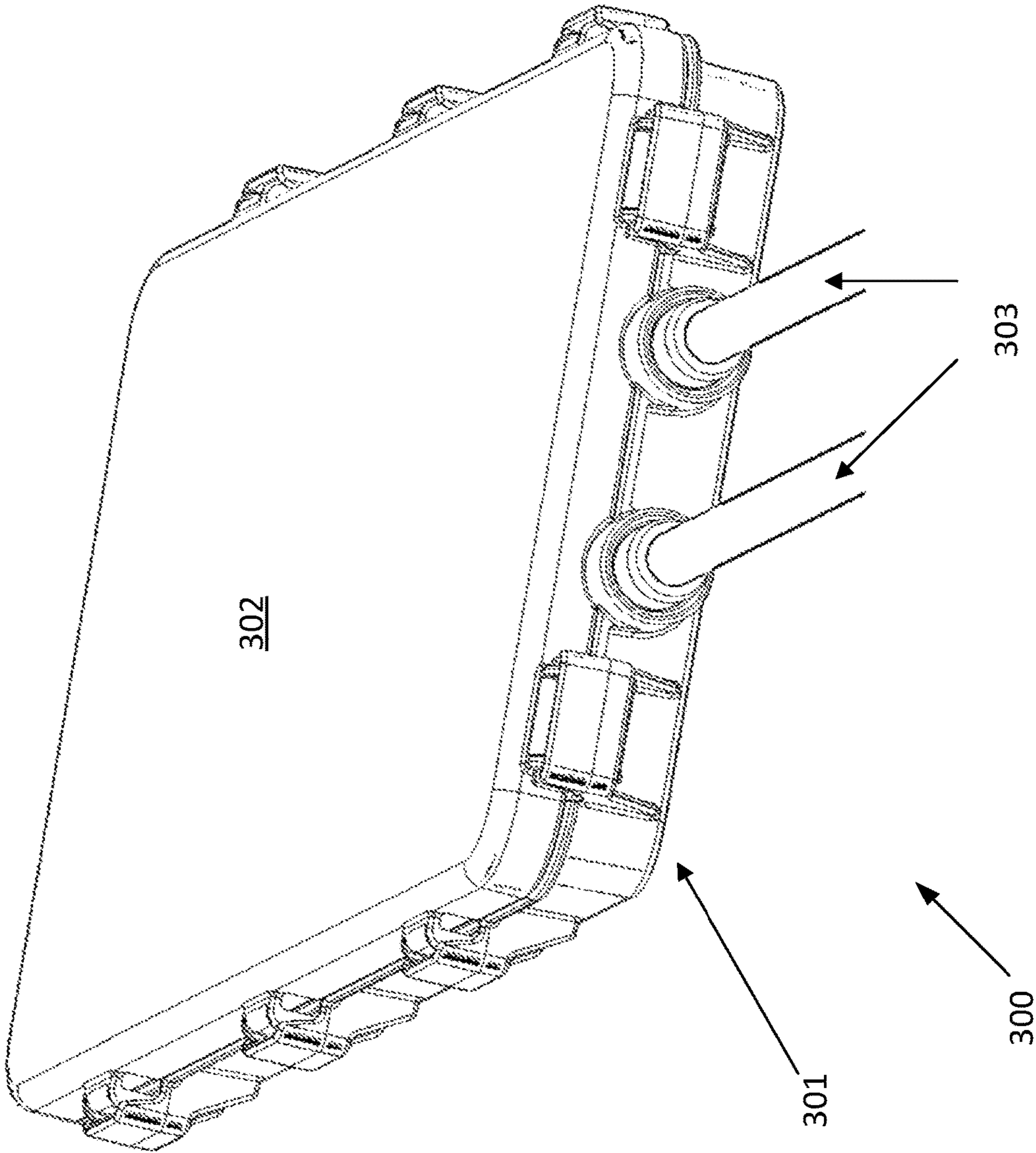
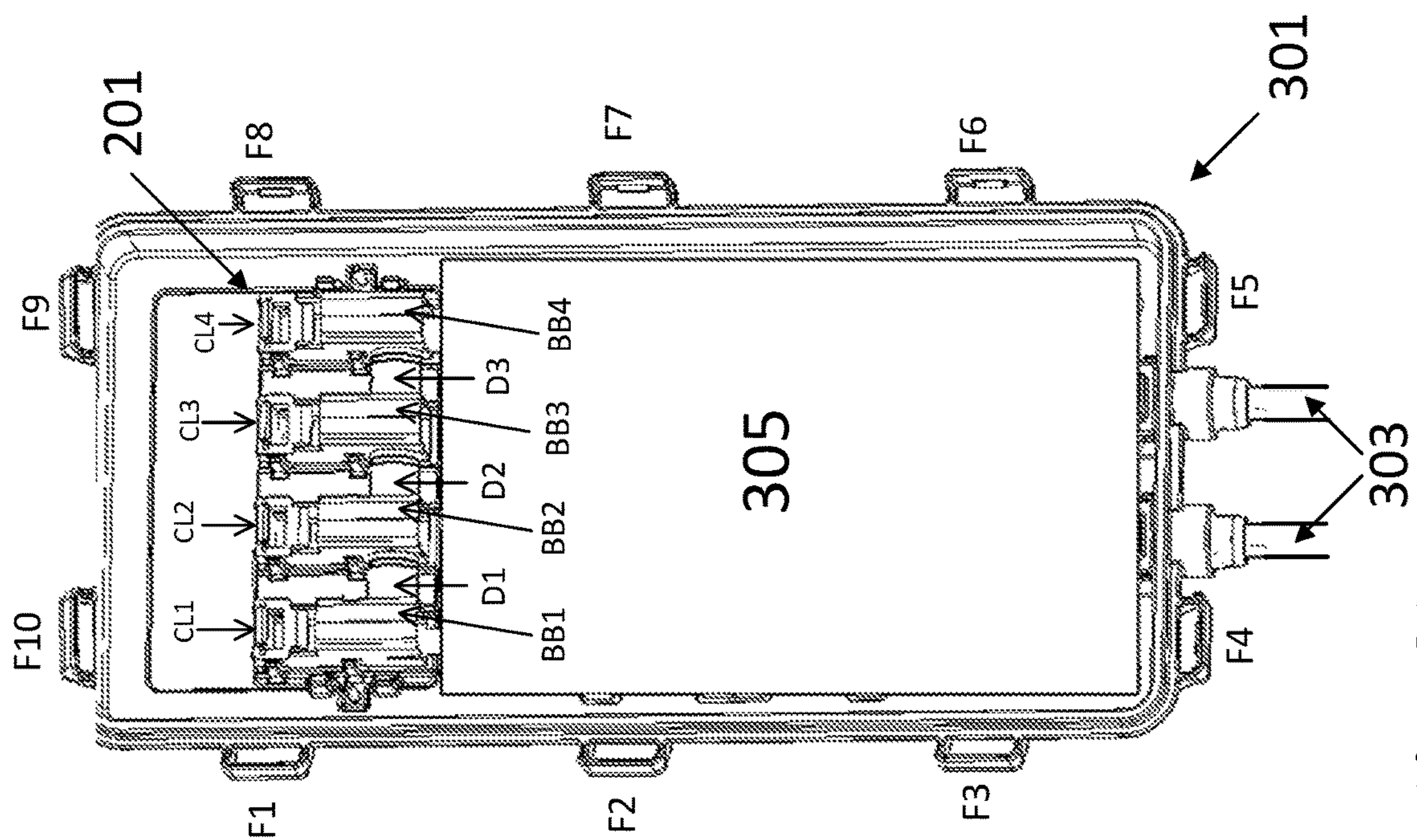


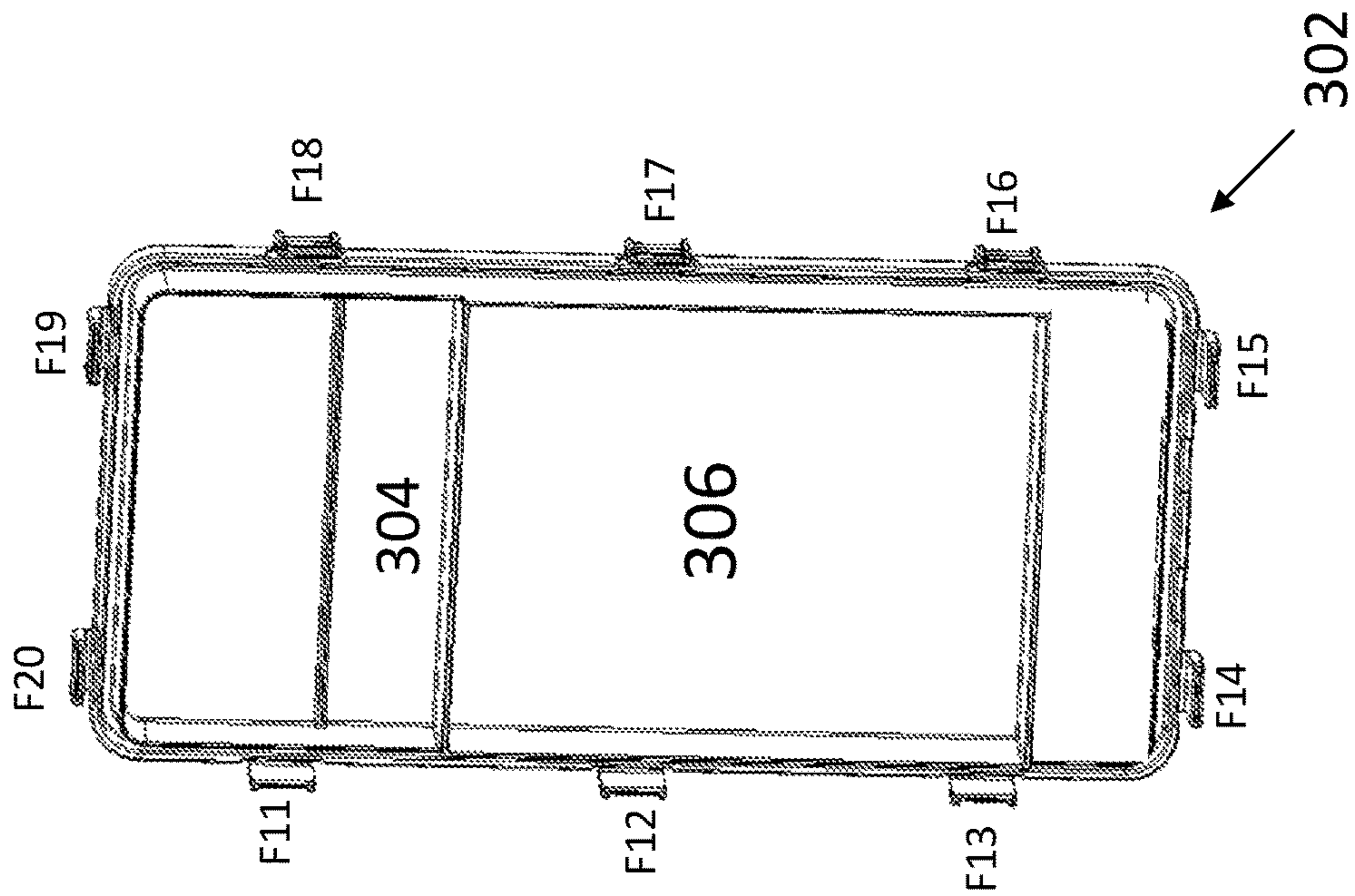
Fig. 2F

Fig. 3A





Fi. 3B



Fi. 30

Fig. 4

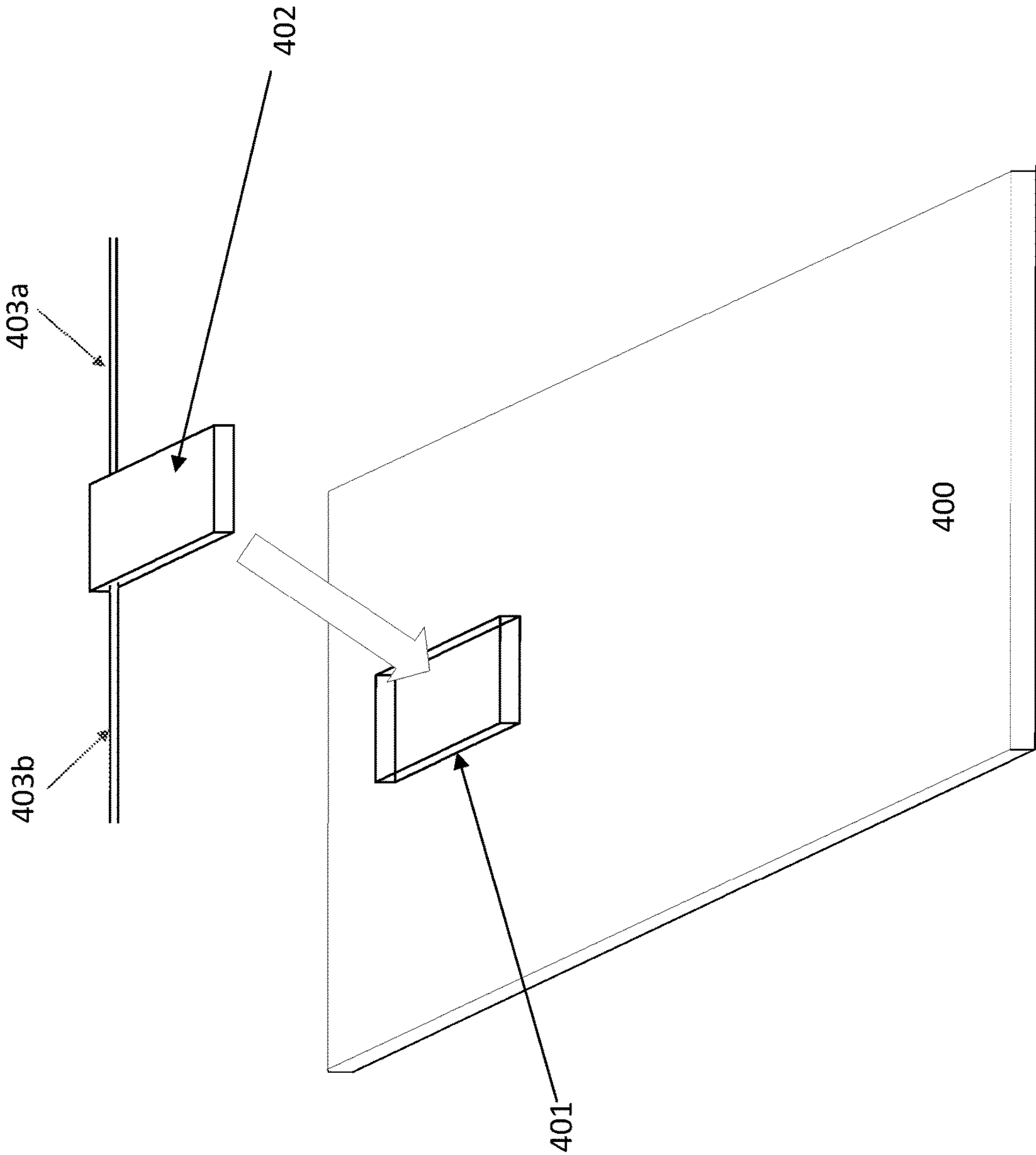
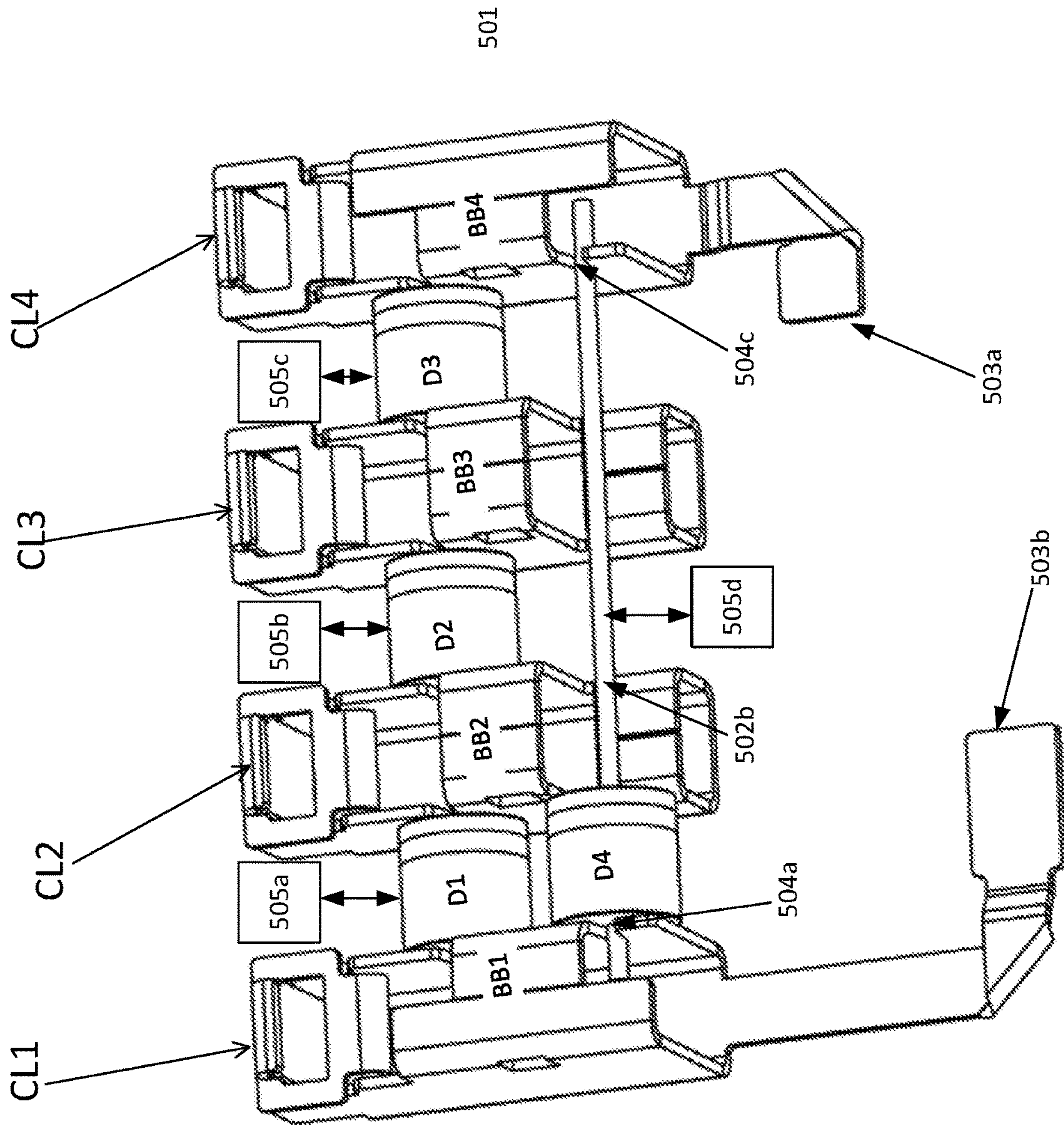


Fig. 5B



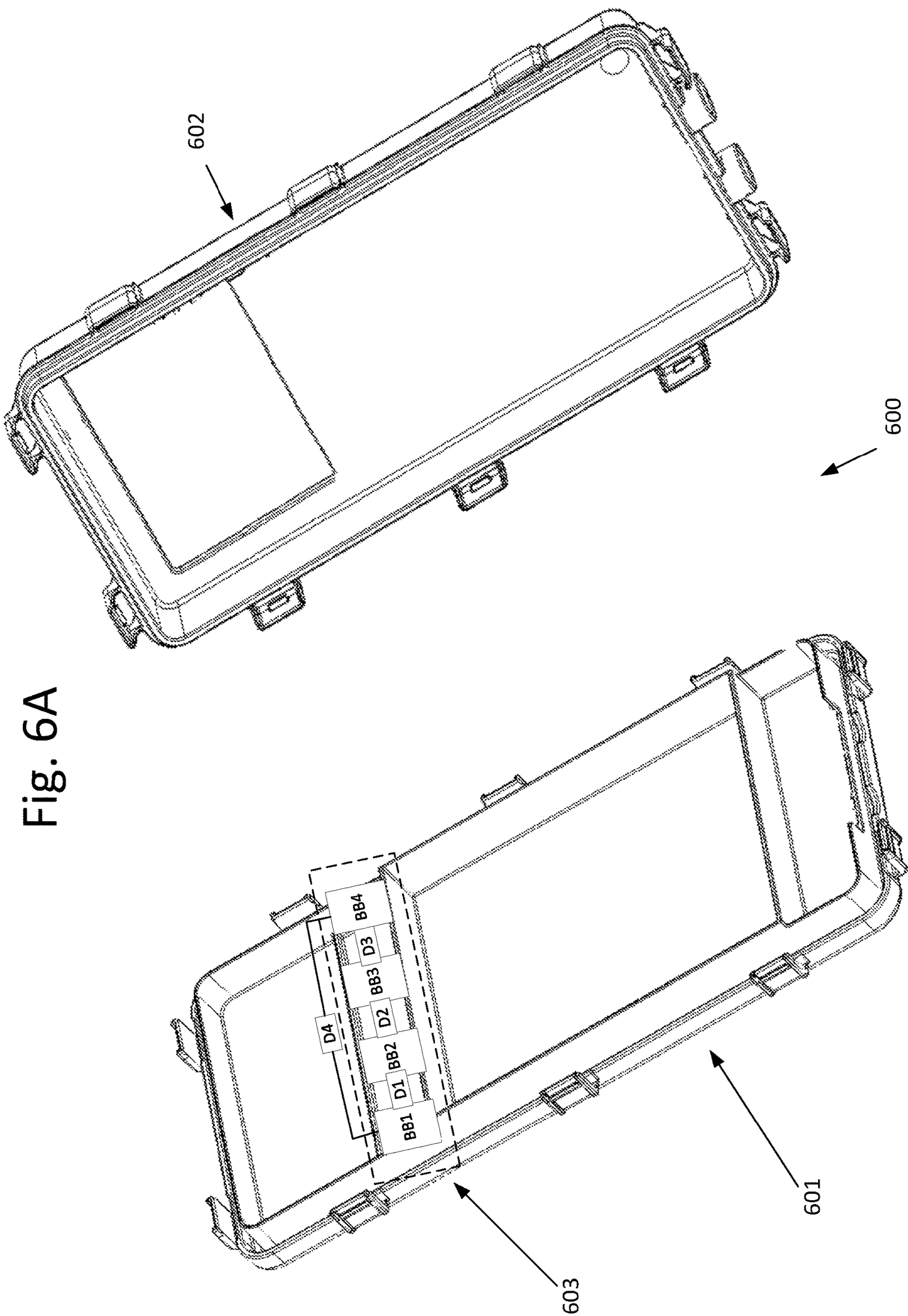


Fig. 6B

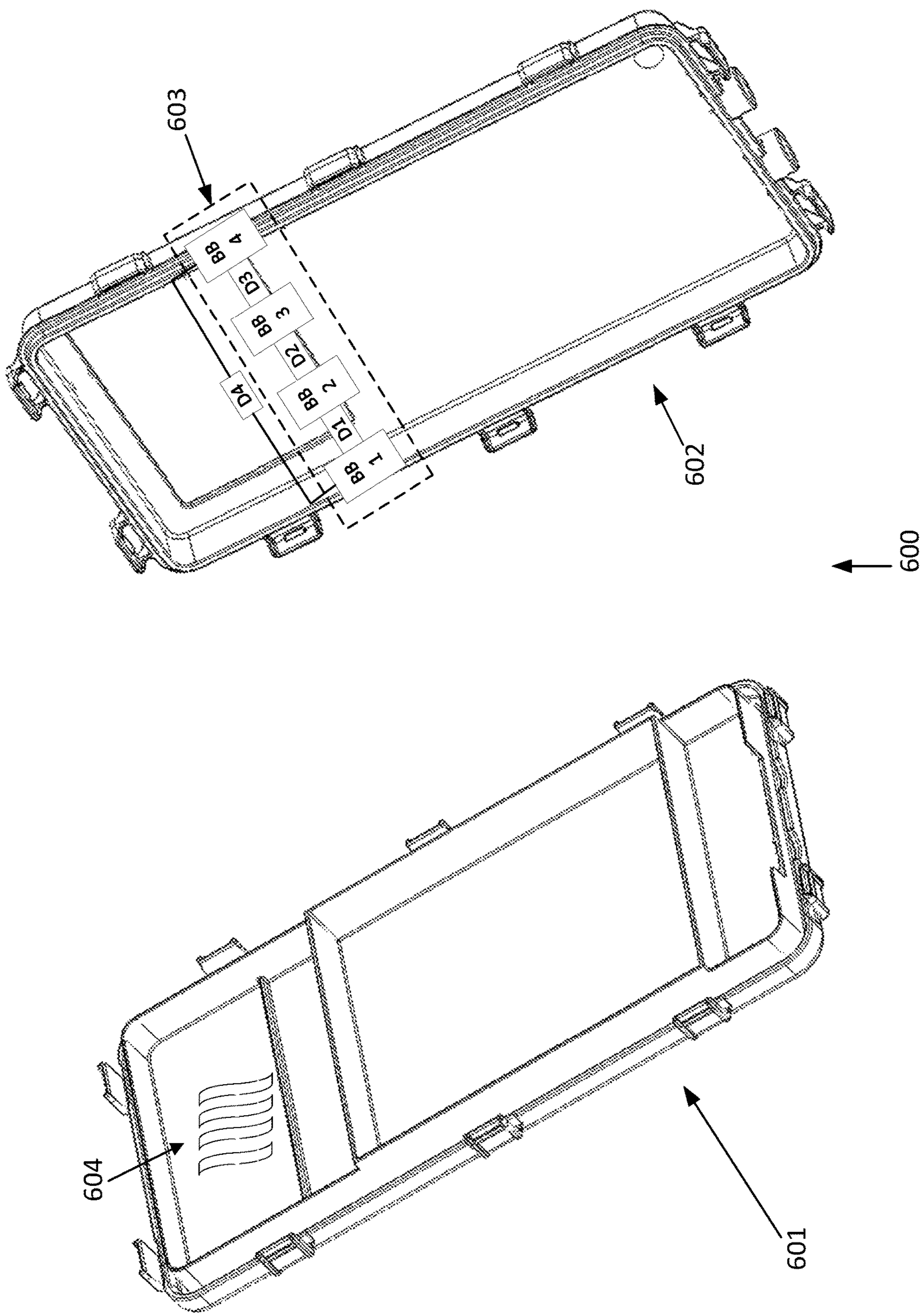
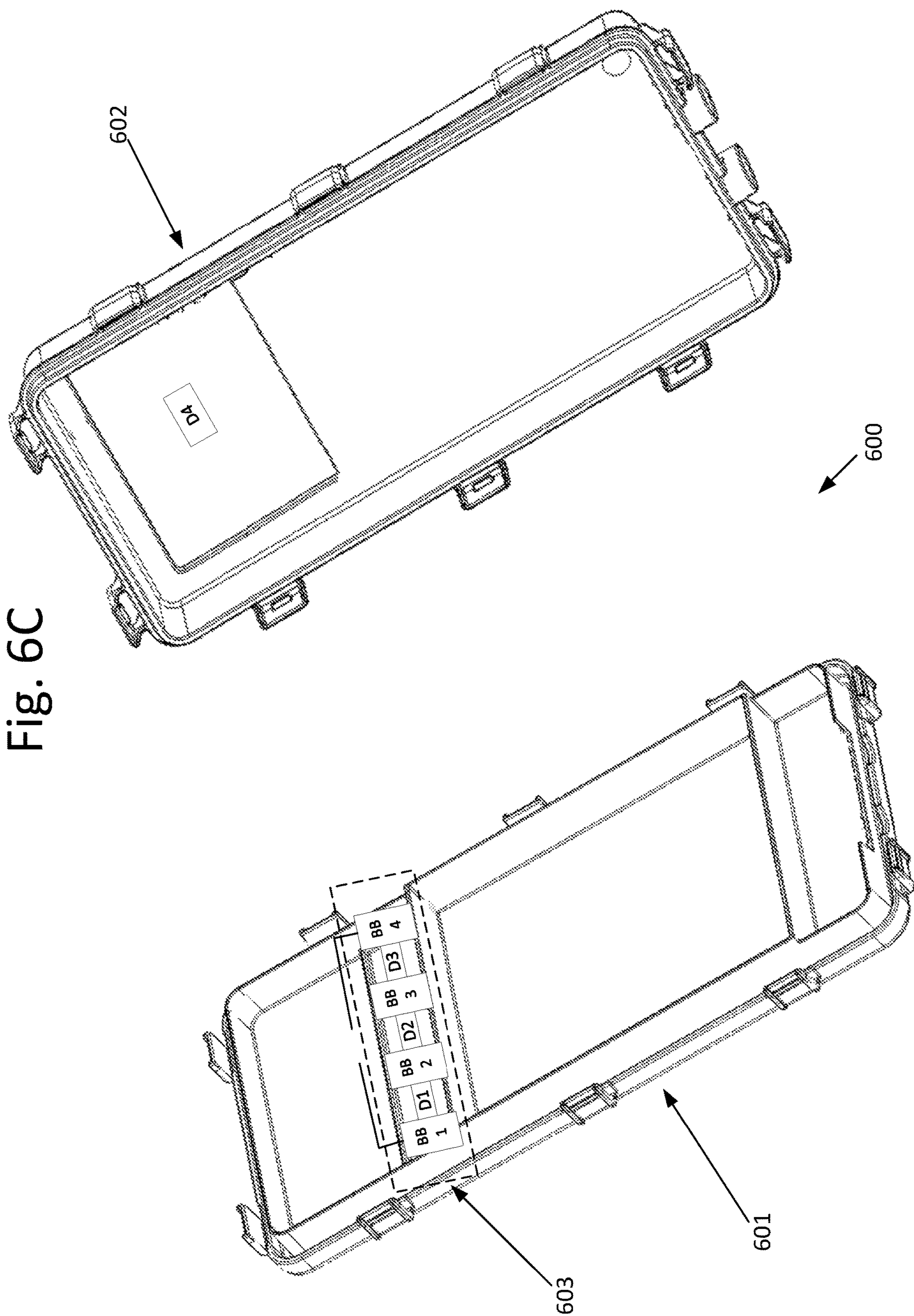


Fig. 6C



HEAT DISSIPATION FOR A PHOTOVOLTAIC JUNCTION BOX

CROSS-REFERENCE TO RELATED APPLICATION

The present application claims priority to and is a non-provisional filing of U.S. Provisional Application Ser. No. 62/478,245, filed Mar. 29, 2017, and entitled "Heat Dissipation for a Photovoltaic Junction Box," the entire contents of which are incorporated by reference herein in their entirety.

BACKGROUND

In many cases photovoltaic panels include one or more substrings of photovoltaic cells. The substrings are connected to each other and may also be connected to diodes. Each one of the diodes may function as a bypass for a respective parallel substring or several substrings. Diodes have a number of disadvantages, including substantial loss of power when current flows through the diodes. As well as power loss, the rise in temperature of the diodes may also be concerning. Because the temperatures may rise more than one would like there is a need for dissipating the heat from the surroundings of the diodes, where today many of the diodes are placed in a small box.

SUMMARY

According to illustrative embodiments disclosed herein, a bypass mechanism is adapted to bypass a photovoltaic (PV) generator, for example, a string or a substring of photovoltaic (PV) cells, and/or a PV panel. The bypass mechanism may be part of a component or circuitry housed in a photovoltaic junction box. The component may include a number of bypass mechanisms, the number which may be based according to the number of strings or substrings electrically coupled to the junction box. The component housed in the junction box may include links connecting the bypass mechanisms, also referred to as bus bars. In addition to serving as connecting links between the bypass mechanisms, the bus bars may also function as heat spreaders. The bypass mechanisms may extract substantial heat due to electrical currents flowing through the bypass mechanisms. The bus bars and bypass mechanisms may be designed and disposed in/on the junction box to effectively dissipate the extracted heat, and to avoid damage to the bypass mechanism or other components or circuitry which may be housed in the junction box. According to some aspects of the disclosure, the bus bars may spread heat the junction box cover and the cover may function as a heat sink. According to some aspects of the disclosure the bus bars may spread heat to the junction box base, and the junction box base may transfer the heat to the PV generator and to the environment. According to some aspects of the disclosure, the bus bars may spread heat to both the junction box cover and the junction box base. According to some aspects of the disclosure, other heat-spreading elements may be disposed in the junction box and designed to spread heat in multiple directions.

According to some aspects, the bypass mechanisms may be housed in and mounted to the base of the junction box, and may be permanently electrically coupled to the PV generator. According to some aspects of the disclosure, the bypass mechanisms may be mounted to the cover of the junction box, and may be electrically coupled to the PV

generator only when the junction box cover is placed on the junction box base. The junction box may also house other components and/or circuitry, for example, a direct current to direct current (DC/DC) converter, a direct current to alternating current (DC/AC) converter, sensor(s)/sensor interface(s), safety devices (e.g. safety switch(es), fuse(s), relay(s), an arc-detection circuit, an arc suppression circuit, a ground-fault detector-interrupter circuit), communication module(s), control device(s) and/or monitoring modules.

According to some aspects, the number of bypass mechanisms may be the same as the number of substrings in the PV generator. According to some aspects of the disclosure, one or more additional bypass mechanisms may be coupled in a parallel configuration to the other bypass mechanisms, so that when a plurality of PV strings or substrings are bypassed, electrical losses may be reduced by allowing current to flow through a current path having fewer (e.g. one or two) bypass mechanisms.

According to some aspects, a plurality of bypass mechanisms may all be housed in either the junction box base or the junction box cover. According to some aspects of the disclosure, a first group of one or more bypass mechanisms may be disposed in the base of the junction box, and a second group of one or more bypass mechanisms may be disposed on the cover of the junction box. Distributing a plurality of bypass mechanisms between the base and the cover may, according to illustrative embodiments, increase system safety by having bypass mechanisms disposed in the base, while decreasing heat generation, increasing efficiency of heat dissipation and decreasing electrical losses by providing additional bypass mechanism disposed in the cover.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following description of various illustrative embodiments, reference is made to the accompanying drawings, which form a part hereof, and in which is shown, by way of illustration, various embodiments in which aspects of the disclosure may be practiced. It is to be understood that other embodiments may be utilized and structural and functional modifications may be made, without departing from the scope of the present disclosure.

FIG. 1 is part schematic, part block diagram of a photovoltaic (PV) generator in accordance with one or more illustrative embodiments.

FIG. 2A illustrates a view of part of a PV generator electrical circuit in accordance with one or more illustrative embodiments.

FIG. 2B is part schematic, part block diagram of a PV system in accordance with one or more illustrative embodiments.

FIGS. 2C-2F illustrate four different configurations in a part schematic, part block diagram of a PV generator electrical circuit in accordance with one or more illustrative embodiments.

FIG. 3A illustrates a view of a PV generator junction box in accordance with one or more illustrative embodiments.

FIG. 3B illustrates an embodiment of a junction box base, in accordance with one or more illustrative embodiments.

FIG. 3C illustrates an embodiment of a junction box cover in accordance with one or more illustrative embodiments.

FIG. 4 is an illustrative sketch of elements of a PV generator junction box and a PV generator, in accordance with one or more illustrative embodiments.

FIG. 5A-5B illustrate two different configurations of a PV generator electrical circuit in accordance with one or more illustrative embodiments.

FIG. 6A is a part schematic, part block diagram of a PV generator junction box with cover removed and associated circuitry wherein the associated circuitry is mounted on the PV generator junction box base in accordance with one or more illustrative embodiments.

FIG. 6B is a part schematic, part block diagram of a PV generator junction box with cover removed and associated circuitry wherein the associated circuitry is mounted on the PV generator junction box cover in accordance with one or more illustrative embodiments.

FIG. 6C is a part schematic, part block diagram of a PV generator junction box and associated circuitry wherein some of the associated circuitry is mounted on the PV generator junction box base and some of the associated circuitry is mounted on the PV generator junction box cover in accordance with one or more illustrative embodiments.

DETAILED DESCRIPTION

In the following description of various illustrative embodiments, reference is made to the accompanying drawings, which form a part hereof, and in which is shown, by way of illustration, various embodiments in which aspects of the disclosure may be practiced. It is to be understood that other embodiments may be utilized and structural and functional modifications may be made, without departing from the scope of the present disclosure.

Photovoltaic (PV) systems may include one or more PV generators. Each PV generator may include one or more photovoltaic cell(s), cell string(s), cell substring(s), module(s), panel(s), shingle(s) and/or solar roof tiles. The one or more PV generators (and/or the photovoltaic cells comprising a larger PV generator) may be interconnected in a serial configuration, a parallel configuration and/or a combination thereof. Current paths may be provided for bypassing one or more photovoltaic cells or PV generators. For example, a PV generator such as a PV panel may include a number of substrings of photovoltaic cells which are configured in a serial arrangement. One or more substrings may have a bypass mechanism providing an alternative current path, allowing current to bypass an associated substring in the event of drop in a current capability of the substring, to avoid forcing a large current through the photovoltaic cells comprising the substring which may lead to large power dissipation and/or damage to the associated photovoltaic cells. Bypass mechanisms might not be entirely lossless, leading to potential power dissipation when current flows through the bypass mechanisms. It may be desirable to reduce the electrical power loss dissipated by bypass mechanisms, as well as provide effective methods for reducing and dissipating heat generated by current flowing through bypass mechanisms.

Reference is made to FIG. 1, which illustrates a photovoltaic (PV) generator **100** with circuitry coupled to the PV generator according to aspects of illustrative embodiments. According to some aspects of the disclosure, a PV generator may be a PV panel. A PV panel may have one or more substrings while each one of the substrings may be electrically accessible via two or more conductors. According to some aspects of the disclosure, PV generator **100** may include a first substring **SS1**, a second substring **SS2**, and a third substring **SS3**. Each of substrings **SS1-SS3** may include a plurality of photovoltaic cells coupled in series, in parallel or in a mixed serial-parallel arrangement. Substrings **SS1-SS3** may be coupled in series. Substring **SS1** may be connected between conductors **102a** and **102b**, substring **SS2** may be electrically accessible via conductors **102b** and

102c, and substring **SS3** may be electrically accessible via conductors **102c** and **102d**. Conductors **102a-d** may connect substrings **SS1-SS3** to junction box **101**. According to some aspects of the disclosure, conductors **102a-d** may include ribbon wire.

A photovoltaic panel may have one or more substrings wherein each substring may be connected to a junction box with two conductors. According to some aspects of the disclosure, Junction box **101** may provide an interface between substrings **SS1-SS3** and output conductors **103a** and **103b**, which may output the power generated by PV generator **100**. Junction box **101** may provide one or more bypass mechanisms (e.g. passive bypass mechanisms such as diodes and/or active bypass mechanism such as switches) for bypassing one or more of substrings **SS1-SS3**.

According to some aspects, junction box **101** may further include additional circuitry. For example, junction box **101** may have one or more power converters (e.g. DC/DC or DC/AC converters) for converting power generated by substrings **SS1-SS3**. According to some aspects of the disclosure, junction box **101** may provide a single power converter for converting the combined power generated by substrings **SS1-SS3**. In other embodiments, junction box **101** may have a plurality of power converters, each configured to convert power received from an associated substring. According to some aspects of the disclosure, the single power converter or the plurality of power converters may be configured to increase power drawn from one or more associated substrings by implementing Maximum Power Point Tracking (MPPT) and/or impedance matching. A power converter may increase power drawn from one or more associated substrings by, for example, by regulating a voltage across or current through an associated substring, such that the associated substring operates at a preferred operating point. A power converter may be controlled by a control device, and the control device may be responsive to sensor(s)/sensor interface(s), such as current, voltage, power, temperature and/or solar irradiance sensor(s)/sensor interface(s).

PV panels may additionally or alternatively include a junction-box integrated power converter. The power converter may be, for example, a direct current to direct current (DC/DC) converter according to various topologies, for example, Buck, Boost, Buck/Boost, Buck+Boost, Flyback, Forward, Cuk and charge pump converters. According to some aspects of the disclosure, a power converter may be a direct current to alternating current converter (DC/AC), e.g. an inverter or a micro-inverter.

According to some aspects, junction box **101** might not include an integrated power converter, with an externally connected device affecting and/or setting an operating point for the substrings **SS1-SS3**.

Junction box **101** may include a communication device such as a wired communication device, a wireless communication device, and/or an acoustic communication device, etc. The communication device may include a receiver, monitor and/or transmitter. The communication device may communicate using, for example, Power Line Communications (PLC), other methods of wired communication, Wi-Fi™, ZigBee™, Bluetooth™, cellular communications, other method of wireless communication and/or acoustic communication. The communication device may be communicatively coupled to one or more controllers configured to control other components in junction box **101**, such as a power converter, safety mechanism and/or sensor(s)/sensor interface(s). The communication device may enable junction box **101** to communicate with other junction boxes having communication devices, and/or additional power devices in

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the same system or in other systems. Junction box **101** may include one or more safety switches which may be controlled by a controller. The safety switches may be used to disconnect PV generator **100** or sections thereof from other parts of the PV system, and/or to short-circuit one or more of substrings **SS1-SS3** to reduce power generated by one or more of substrings **SS1-SS3**.

Junction box **101** may be mechanically mounted onto PV generator **100**. A bypass mechanism may be provided so that one or more of substrings **SS1-SS3** may be bypassed under certain conditions. For example, if substring **SS1** is shaded and/or underperforming it may be bypassed to avoid affecting an operating point of substrings **SS2** and **SS3** and potentially lowering output power of substrings **SS2** and **SS3**.

If substring **SS1** is shaded and/or underperforming, it may be bypassed to avoid a current being forced through substring **SS1** which may result in power loss, overheating and/or damage to substring **SS1**. The bypass mechanism may include a passive element such as a diode, and/or an active element such as a controlled switch (e.g., MOSFET, IGBT, BJT, and/or relay switch). According to some aspects of the disclosure, the bypass mechanism may be part of a power device configured to convert power harvested from PV generator **100**. The bypass mechanism may be housed in junction box **101** which may be mounted onto PV generator **100**.

Reference is now made to FIG. 2A, which illustrates a PV panel junction box component **201** according to aspects of illustrative embodiments. Junction box **101** of FIG. 1 may include a junction box component **201**, as depicted in FIG. 2A. A PV generator comprising a number of photovoltaic cell substrings or a number of PV cells configured in a string array, may include a number of bypass mechanisms. FIG. 2A illustrates a junction box component **201** including one or more bypass mechanisms such as bypass mechanisms **D1**, **D2**, **D3** according to an illustrative embodiment. Junction box component **201** may include a first bypass mechanism **D1**, a second bypass mechanism **D2** and a third bypass mechanism **D3**. In the illustrative embodiment of FIG. 2A, bypass mechanisms **D1-D3** are diodes. In alternative embodiments, a controlled switch (e.g., a MOSFET) may be used to reduce bypass losses (i.e., the power lost as a result of activation of a bypass mechanism). Bypass mechanism **D1** may bypass a first section, photovoltaic cell or substring of a PV panel which may be electrically coupled to junction box component **201** between a first connector location **CL1** and a second connector location **CL2**. Bypass mechanism **D2** may bypass a second section, photovoltaic cell or substring of a PV panel which may be electrically coupled to junction box component **201** between a first connector location **CL2** and a second connector location **CL3**. Bypass mechanism **D3** may bypass a third section, photovoltaic cell or substring of a PV panel which may be electrically coupled to junction box component **201** between a first connector location **CL3** and a second connector location **CL4**. Connectors in connector locations **CL1-CL4** may be suitable for receiving conductors coupled to photovoltaic substrings. For example, the connectors at connector locations **CL1-CL4** may include ribbon wire receptacles.

Junction box component **201** may have a first output conductor **203a** and a second output conductor **203b**. Output conductors **203a** and **203b** may transfer power to a power device (e.g., a power converter or a safety device) or to output terminals of a PV generator (e.g., output terminals of a PV panel). Other embodiments may feature a different number of bypass mechanisms corresponding to the number

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of photovoltaic elements which are designed with a bypass. For example, a PV generator comprising five serially coupled substrings may include five bypass mechanisms. As another example, a single substring of twenty photovoltaic cells may include twenty bypass mechanisms, one for each photovoltaic cell. In a different embodiment there may be twenty photovoltaic cells divided into four groups of five cells and there may be four bypass mechanisms, one for each group.

According to some aspects, when current enters a power generator through an output conductor **203a** of junction box component **201**, it may first flow through a conducting bus bar **BB1**. If a PV generator (e.g., substring **SS1** of FIG. 1) coupled between connection locations **CL1** and **CL2** is operating at a capacity which supports the current flowing through output conductor **203a**, the entire current may flow through the coupled PV generator to bus bar **BB2**. Similarly, if a PV generator (e.g. substring **SS2** of FIG. 1) coupled between connection locations **CL2** and **CL3** is operating at a capacity which supports the current flowing through output conductor **203a**, the entire current may flow through the coupled PV generator to bus bar **BB3**. Similarly, if a PV generator (e.g. substring **SS3** of FIG. 1) coupled between connection locations **CL3** and **CL4** is operating at a capacity which supports the current flowing through output conductor **203a**, the entire current may flow through the coupled PV generator to bus bar **BB4**.

If a PV generator coupled between two bus bars is unable to carry the full current, forcing the full current through the PV generator may cause a reverse voltage to develop between two bus bars, which may, in turn, result in the bypass mechanism turning ON. In the illustrative embodiment of FIG. 2A, providing diodes between bus bars may cause automatic bypassing in case of reverse voltage between bus bars. According to some aspects of the disclosure, an active switch may be disposed between bus bars and may be set to the ON position in response to detection of a reverse voltage condition. For example, a voltage sensor may measure a voltage between two bus bars and provide voltage measurements to a controller. Upon detecting a voltage indicative of a reverse voltage condition, the controller may set a switch disposed between the two bus bars to the ON position.

Providing bypass paths may reduce total system power loss and/or prevent damage to equipment, and may also cause a rise in temperature in certain components or at certain locations in junction box component **201**. One of the components that may experience a rise in temperature is the bypass mechanism. For example, bypass diodes may generate significant heat when carrying currents typical of PV generators (e.g., **8A**, **10A** or even more). Depending on the current which may flow through the bypass mechanism and the characteristics of the bypass mechanism, there may be a need to extract heat from one or more bypass mechanisms. Various heat-dissipation methods exist, including leveraging different ways heat may transfer such as conduction, convection and radiation, which may be employed with the configurations discussed herein. In one embodiment, a fan (not shown) may be positioned in junction box **101** (FIG. 1) in order to transfer the heat from the overheated bypass mechanism's which may cause a relatively high convection coefficient compared to the convection coefficient of standing air. In a second embodiment, cooler agents such as water (not shown) may be positioned in a manner avoiding harm to the electrical circuit but still transferring the heat faster than standing air would, such as a phase change cooler. In a third embodiment cryogenic coolers (not shown) may be

used to lower specific heat spots. According to some aspects of the disclosure, enhanced cooling may include changing a conductive coefficient associated with elements thermally coupled to components which are to be cooled. A first way to improve the conductive coefficient may include changing a design or shape of various components and their assembly design. A second way to improve a conductive coefficient may include adding heat dissipation mechanisms which may increase the heat-transfer rate. For example, applying thermal grease (not shown) between junction box component and junction box. Thermal pads, thermal putty, thermal paste and/or laminated Kapton® polyimide film may be used instead of or in addition to thermal grease for transferring the heat from one or more bypass mechanisms.

Bus bars BB1-BB4 as illustratively depicted in FIG. 2A show another example for improving a conductive coefficient and transferring heat quickly so that the bypass mechanisms do not overheat. Bus bars BB1-BB4 may be coupled to bypass mechanisms D1-D3, and may be housed in the base of junction box 101 (FIG. 1). When current flows through bypass mechanisms D1-D3, the temperature at bypass mechanisms D1-D3 may rise. Bus bars BB1-BB4, which may be conductive, may draw and evacuate the heat to the base of junction box 101 and through an associated power generator, keeping the temperature under an acceptable threshold. In another embodiment, bus bars BB1-BB4 may transfer heat towards the cover of junction box 101 (FIG. 1), and from the cover to the environment.

When bus bars BB1-BB4 spread heat in more than one direction, for example, a first direction towards the base of junction box 101 and a second direction towards the cover of junction box 101, they may be referred to as multi-directional heat spreaders. In embodiments featuring bus bars BB1-BB4 additionally functioning as heat spreaders, the walls of junction box 101 may function as heat sinks. Bus bars BB1-BB4 may also be designed to spread heat to a third and fourth direction. According to some aspects of the disclosure, bus bars BB1-BB4 may include cooling fins designed in one or more shapes and extending in one or more directions.

Reference is now made to FIG. 2B, which illustrates a PV string section 205 including a string of coupled PV generators 200a-200d according to aspects of one or more illustrative embodiments. PV string section 205 may include a plurality of PV generators, e.g., four PV generators 200a-200d as depicted in FIG. 2B. PV generators 200a-200d may each include one of junction boxes 202a-202d, respectively, and junction boxes 202a-202d may each include junction box components 201a-d, respectively. Junction box components 201a-d may be designed and have the same components as junction box component 201 of FIG. 2A, such as: connection locations CL1-CL4, bypass mechanisms D1-D3, bus bars BB1-BB4 and output conductors 203a and 203b. For example, junction box component 201b may be coupled to junction box component 201a of junction box 202a and PV generator 200a via conductor 210a and may be coupled to junction box component 201c of junction box 202c and PV generator 200c via conductor 210b. Conductor 210a may be coupled between a first output conductor 203a of junction box component 201b and a second output conductor 203b of junction box component 201a.

Reference is now made to FIGS. 2C-2F which illustrate part of a PV generator junction box according to aspects of illustrative embodiments. Bus bars BB1-BB4 and bypass mechanisms D1-D3 may be the same as bus bars BB1-BB4 and bypass mechanisms D1-D3 of FIG. 2A. According to some aspects of the disclosure bus bars BB1-BB4 may all or

partially include additional heat spreaders which may cover partially or fully one or more of the bypass mechanisms D1-D3. The additional heat spreaders may be flat or may include fins, such as straight or pin shaped fins. The additional heat spreaders may be made of effective heat-spreading materials, such as metal, or a material having heat-spreading capabilities.

FIG. 2C illustrates illustrative embodiments where bus bars BB1-BB4 may be multi-directional heat spreaders, spreading heat towards a base 206c of a PV power generator junction box and a cover 207c of the PV power generator junction box. In addition, providing multi-directional heat spreading, bus bars BB1-BB4 may include one or more additional heat spreaders R1a-R4a which may have a larger surface area than bus bars BB1-BB4. According to some aspects of the disclosure, heat spreaders R1a and R2a may partially or fully cover bypass mechanism D1 and heat spreaders R3a and R4a may partially or fully cover bypass mechanism D3. Heat spreaders R1a-R4a may be flat or may have fins, such as straight or pin shaped fins. Including heat spreaders R1a-R4a may spread heat at a more effective rate.

With reference to FIG. 2D, heat spreaders R2b and R3b may extend to cover part or all of bypass mechanism D2. If heat spreaders R2b and R3b are made of electrically conductive material, a gap may be maintained between heat spreaders R2b and R3b to avoid short-circuiting bypass mechanism D2.

FIG. 2E illustrates some embodiments where BB1-BB4 may be multi-directional heat spreaders, spreading heat in the direction of a base 206e of a PV power generator junction box and a cover 207e of the PV power generator junction box. Bus bars BB2-BB3 may include additional heat spreaders on one end R5a and R6a which may have larger surface areas than bus bars BB2 and BB3 and therefore may increase the rate of the heat dissipation. Heat spreaders R5a and R6a may be attached to the tops of bus bars BB2 and BB3, respectively, and may extend horizontally to partially or fully cover bypass mechanisms D1 and D3, which may provide enhanced vertical heat spreading. According to some aspects of the disclosure, heat spreaders R5a and R6a may be flat portions of heat-conducting material, and according to some aspects, heat spreaders may be shaped for enhanced heat spreading (e.g. using slats and/or other heat-sink design patterns). According to some aspects of the disclosure, central bus bars BB2 and BB3 may rise to a higher temperature than peripheral bus bars BB1 and BB4 which are closer to the exterior of the junction box. Adding more material to bus bars BB2 and BB3 in order to spread heat may improve the conductive coefficient and keep the temperature under a certain threshold. According to some aspects of the disclosure it may be more efficient to add more surface area and material to bus bars BB2-BB3 rather than adding less material and surface area to bus bars BB1-BB4. Heat spreaders R5a and R6a may partially or fully cover bypass mechanism D1 and D3 respectively. If heat spreader R5a is made of electrically conductive material, a gap may be maintained between heat spreader R5a and bus bar BB1 to avoid short-circuiting bypass mechanism D1. If heat spreader R6a is made of electrically conductive material, a gap may be maintained between heat spreader R6a and bus bar BB4 to avoid short-circuiting bypass mechanism D3.

With reference to FIG. 2F, heat spreaders R5b and R6b may extend to cover part or all of bypass mechanism D2. If heat spreaders R5b and R6b are made of electrically con-

ductive material, a gap may be maintained between heat spreaders **R6b** and **R6b** to avoid short-circuiting bypass mechanism **D2**.

Reference is now made to FIG. 3A-3C which illustrate parts of a PV generator junction box according to aspects of illustrative embodiments. A junction box **300** may be the same as or similar to junction box **101** of FIG. 1. Junction box **300** may include a base **301** and a cover **302**. Base **301** may include a bottom designed to be attached to a non-photovoltaic part of a photovoltaic generator (e.g. a back side, or a side bar) and an opening designed to be covered. Junction box **300** may also include output conductors **303**. In some photovoltaic strings, conductors **303** may be coupled to junction boxes providing power collected from other photovoltaic generators. According to some aspects, conductors **303** may be coupled to a power device (e.g., a DC/DC converter, a DC/AC inverter, a safety device and/or a monitoring device) and may be coupled to a PV power system device. Conductors **303** may be the same or similar to output conductors **103a** and **103b** of FIG. 1.

Reference is now made to FIG. 3B, which illustrates a junction box base **301** of junction box **300** of FIG. 3A, according to illustrative embodiments. Junction box component **201** may be housed in the inner side of base **301**. Conductors **303** may be coupled to junction box component **201** and may extract output current or power from junction box component **201**. Junction box base **301** may include one or more locks which may have corresponding locks and/or receptacles on junction box cover **302** (of FIG. 3C) designed to lock junction box base **301** to junction box cover **302**. For example, junction box base **301** may have click-on locks **F1-F10** which may be coupled to corresponding receptacles on a top to the junction box. According to some aspects of the disclosure, junction box base **301** may include area **305** for housing additional circuitry (e.g., power devices, as explained above) coupled between output conductors **303** and junction box component **201**.

Reference is now made to FIG. 3C, which illustrates a junction box cover **302** of junction box **300** of FIG. 3A, according to illustrative embodiments. Junction box cover **302** may include receptacles **F11-F20** which are configured to click onto click-on locks (for example, click-on locks **F1-F10** of FIG. 3B). Area **304** in cover **302** may include a heat dissipation mechanism, for example, thermal grease, thermal pads, thermal putty, thermal paste, or a phase changer. The heat dissipation mechanism at area **304** may be thermally coupled to junction box component **201** when base **301** is covered by cover **302**, which may help bus bars **BB1-BB4** of junction box component **201** spread heat across cover **302** and prevent the heat from concentrating in specific hot spots. According to some aspects of the disclosure, junction box cover **302**, at or under area **304**, may include a section made of a material (e.g., polyphenylene sulfide, polyetherimide, polyethersulfone) with certain characteristics which may withstand heat dissipated from the bypass mechanisms in junction box component **201**. Junction box cover **302** may be mostly made of a first material selected to withstand a first temperature, and a section (e.g., at area **304**) of junction box cover **302** may be made of a second material selected to withstand a second temperature which may be higher than the first temperature. In other embodiments (not shown), junction box component **201** may be mounted onto cover **302**. According to some aspects of the disclosure, cover **302** may include area **306** for housing additional circuitry (e.g., power devices, as explained above) to be coupled between output conductors

303 and junction box component **201** when junction box base **301** is attached to junction box cover **302**.

According to some aspects in which junction box **300** includes a power device, the power device, like junction box component **201**, may be mounted on base **301** or may be mounted on cover **302**. The power device may include a DC/DC converter, a power point tracker (PPT), an external bypass system, a DC/AC converter, a control system, a signaling mechanism, signal receiver or monitor and/or one or more sensors/sensor interfaces such as temperature, voltage or current sensors.

Reference is now made to FIG. 4 which illustrates a PV power generator and parts of a PV power generator junction box according to aspects of illustrative embodiments. According to some aspects of the disclosure, a PV generator **400** may be a photovoltaic panel and may have one or more substrings (e.g. substrings similar to substrings **SS1-SS3** of FIG. 1). Junction box base **401** may be mounted on a side of PV generator **400**. PV power generator **400** may include a number of substrings (similar to as shown in FIG. 1). According to some aspects of the disclosure, junction box base **401** may include additional circuitry, such as a control unit, a power converter, a communication device, a power device, a safety device, a sensor interface, a signaling mechanism, a switch or a system device. Junction box cover **402** may be designed to connect to and cover junction box base **401**. According to some aspects, instead of or in addition to installing, integrating or mounting circuitry on junction box base **401**, additional circuitry may be mounted on, installed in or integrated in junction box cover **402**, with the circuitry and junction box components designed to electrically connect the circuitry to corresponding circuitry on the junction box base side. Mounting circuitry on junction box cover **402** may increase ease of repairing and replacing. For example, if circuitry mounted on junction box cover **402** malfunctions, a replacement may be quick and easy: the junction box cover **402** may be removed and replaced with a different junction box cover **402** comprising new circuitry.

Power generated by PV generator **400** may be output via conductors **403a** and **403b**. According to some aspects of the disclosure, conductors **403a** and **403b** may be coupled to junction box base **401** (not shown). In the illustrative embodiment shown in FIG. 4, conductors **403a** and **403b** may be coupled to junction box cover **402**, and when cover **402** is placed on junction box base **401** conductors **403a** and **403b** may receive power delivered through junction box base **401**. Conductors **403a** and **403b** may be pre-coupled (e.g. during manufacturing) to junction box cover **402**. Pre-coupling conductors **403a** and **403b** to junction box cover **402** may increase ease and/or speed of installation. For example, if conductors **403a-b** connect to junction box base **401**, at installation, junction box cover **402** would be connected to junction box base **401**, and conductors **403a** and **403b** would need to be coupled to junction box base **401**. By pre-coupling conductors **403a** and **403b** to junction box cover **402** (e.g., during manufacturing), at installation of junction box cover **402**, junction box cover **402** may be mounted onto junction box base **401** and fewer steps may be required. In PV systems including a large number of junction box installations, reducing a need to couple conductors to their respective junction boxes may save a lot of time and make installation easier for the installer.

According to some aspects, a plurality of junction box covers **402s** may be coupled using conductors (e.g. **403a**, **403b**) prior to deploying in a PV system. For example, a plurality of junction box covers **402** may be pre-coupled

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during manufacturing, each pair of junction box covers coupled by a conductor having a length corresponding to a length or width of a PV generator **400**. Pre-coupling junction box covers **402** may further decrease installation time, and may provide substantial costs savings (e.g., by saving the cost of connectors such as MC4 connectors for connecting separate junction box covers **402**).

Reference is now made to FIGS. **5A** and **5B** which illustrate a PV generator junction box component **501** according to aspects of illustrative embodiments. Junction box component **501** may include output conductors **503a** and **503b**, bus bars BB1-BB4, conductor connectors CL1-CL4 and bypass mechanisms D1-D3 which may be the same or similar to bus bars BB1-BB4 and bypass mechanisms D1-D3 of FIG. **2A**. In addition to bypass mechanisms D1-D3, junction box component **501** may have a bypass mechanism **D4** configured in a parallel configuration to bypass mechanisms D1-D3. According to some aspects of the disclosure herein, bypass mechanism **D4** may be electrically coupled on a first side to bus bar BB1 and may be electrically coupled on a second side to bus bar BB2. According to some aspects, bypass mechanism **D4** may be electrically coupled on a first side to output conductor **503a**, and on a second side to output conductor **503b**. The electrical coupling between bypass mechanism **D4** and bus bars BB1 and BB4 may be with a conductor. For example, the conductor may include an additional bus bar **502a** or conductive rod **502b**.

FIG. **5A** shows an illustrative embodiment with bypass mechanism **D4** electrically coupled between bus bars BB1 and BB4 using bus bar **502a**. Bus bar **502a** may be manufactured as part of junction box component **501**. Bypass mechanism **D4** may have an input conductor and an output conductor which may connect to bus bars BB1 and **502a** at points **504a-b** using, for example, a clicking mechanism. The clicking mechanism may include points **504a-b** which may be sockets in bus bars BB1 and **502a** respectively, which input and output conductors of bypass mechanism **D4** may click into. As another example, bypass mechanism **D4** may be soldered in place between points **504a** and **504b**.

FIG. **5B** shows an illustrative embodiment with bypass mechanism **D4** electrically coupled between bus bars BB1 and BB4 using conductive rod **502b**. Conductive rod **502b** may be manufactured together with bypass mechanism **D4** as an output conductor, or may be electrically coupled to an output conductor of bypass mechanism **D4** (not explicitly shown). Bypass mechanism **D4** may have an input conductor and an output conductor. The input and output conductors of bypass mechanism **D4** may connect to bus bars BB1 and BB4 at points **504a** and **504c** using a clicking mechanism. The clicking mechanism may include points **504a** and **504c** may be sockets in bus bars BB1 and BB4 respectively, which input and output conductors of bypass mechanism **D4** may click into.

According to some aspects and as shown in FIG. **5B**, junction box component **501** may include current sensors **505a-d**. Current sensors **505a-d** may output the size of current to a communication device which may send the different measurements to a monitoring system. Measuring the current flowing through bypass mechanisms D1-D4 may enable or enhance detection of failures in a PV generator or junction box component **501**. For example, melting of components in a junction box component **501** may cause short-circuit or open-circuit conditions which may affect current measurements.

In a PV system there may be mismatches between the current flowing through certain parts of the system and the

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maximum current supported by other parts of the system such as substrings or single photovoltaic cells. Depending on the nature of the mismatch, it may be desirable to bypass certain parts of the PV system, and in some situations it may be desirable to bypass a plurality of coupled substrings or even an entire PV panel. Each bypass mechanism of FIG. **2A** (i.e., D1, D2 and D3) may be designed to bypass a respective photovoltaic generator (e.g., a PV substring). In an event that all three of the bypass mechanisms of FIG. **2A** are activated, significant electrical losses and heat generation may result. As a numerical example, bypass mechanisms D1-D3 may be diodes having a forward voltage of 0.3V. When all three bypass mechanisms are activated to carry a bypass current of, for example, 10 A, total electrical losses may equal $3 \cdot 0.3 \cdot 10 = 9$ W, which may be converted into heat, resulting in a rise in the temperature of the bypass mechanisms and/or nearby electrical components. Over time, the rising temperature may cause component failure.

Providing additional bypass mechanisms in parallel to bypass mechanisms D1-D3 may reduce the number of bypass mechanisms activated at any single time and reduce losses and heat caused by bypass mechanism activation. For example, FIG. **5A** illustrates a junction box component **501** of a PV panel having three substrings. If all three substrings are mismatched or underperforming with regard to other PV generators, bypass mechanism **D4** may be activated instead of three bypass mechanisms D1-D3. As a numerical example, if bypass mechanism **D4** is similar to bypass mechanisms D1-D3 and is activated to carry a bypass current of 10 A, when bypass mechanism **D4** is activated instead of bypass mechanisms D1-D3, total electrical losses may equal $1 \cdot 0.3 \cdot 10 = 3$ W, or one-third of the losses which would be caused by activating bypass mechanisms D1-D3. Other multiple bypasses are possible (not shown) such as a bypass mechanism between bus bar BB2 and bus bar BB4. A multiple bypass such as this one may take the output from the first substring and bypass the second and the third substrings. Another possible multiple bypass arrangement may include coupling a bypass mechanism between bus bar BB1 and bus bar BB3. A bypass mechanism coupled between BB1 and BB3 may bypass the first and second substring, still allowing the power of the third substring may be harvested. A PV power generator may have more than 3 substrings and the number of possible bypass arrangements may increase.

Reference is now made to FIG. **6A** which is part sketch, part block diagram of a PV generator junction box component **603** mounted in a PV power generator junction box **600** according to aspects of illustrative embodiments. Junction box component **603** may be mounted on a junction box base **601** and may have a first bypass mechanism D1, a second bypass mechanism D2 and a third bypass mechanism D3. Bypass mechanisms D1-D3 may be linked by bus bars BB1-BB4. A fourth bypass mechanism **D4** may be coupled to junction box component **603** between bus bars BB1 and BB4, providing a bypass route between bus bars BB1 and BB4 in parallel to bypass mechanisms D1-D3. Junction box cover **602** may house a heat spreader and/or other circuitry such as a power converter, communication device and/or sensors/sensor interfaces, which may be electrically coupled to junction box component **603** when junction box **600** is closed and junction box cover **602** is mounted onto junction box base **601**.

Reference is now made to FIG. **6B** which is part sketch, part block diagram of a PV generator junction box component **603** mounted in a PV power generator junction box **600** according to aspects of illustrative embodiments. According

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to some aspects of the disclosure, as shown in FIG. 6B, junction box component 603 and bus bars BB1-BB4 may be mounted on a junction box cover 602. Junction box base 601 may house conductors which may link substrings 604 of a PV generator to junction box component 603 when junction box base 601 is mounted on a PV panel and junction box cover is mounted onto junction box base 601.

Reference is now made to FIG. 6C which is part sketch, part block diagram of a PV generator junction box component 603 mounted in a PV power generator junction box 600 according to aspects of illustrative embodiments. According to some aspects of the disclosure, as shown in FIG. 6C, junction box component 603 may be mounted onto junction box base 601. Bypass mechanism D4 may be mounted onto junction box cover 602 and positioned so that when junction box cover 602 is aligned with junction box base 601 and the junction box is closed (i.e. by fastening junction box cover 602 to junction box base 601), bypass mechanism D4 is coupled to junction box component 603. When junction box cover 602 is aligned with junction box base 601 and the junction box is closed bypass mechanism may be coupled to junction box component 603 and may be linked between bus bars BB1 and BB4.

According to some embodiments, disposing bypass mechanisms D1-D4 on junction box base 601 (e.g. as in FIG. 6A) may provide certain safety advantages. For example, bypass mechanisms D1-D4 may be fixed in place (e.g., by soldering or mechanical connection) during manufacturing, to ensure provision of a bypass path in case of a mismatch or underperforming PV generator or string, without risk of an improper manual mechanical connection of the bypass mechanisms.

According to some embodiments, disposing bypass mechanisms D1-D4 on junction box cover 602 (e.g. as in FIG. 6B) may provide certain thermal advantages. For example, dissipation of heat from bypass mechanisms mounted on junction box cover 602 to the environment may be faster and more effective than dissipation of heat from bypass mechanisms mounted on junction box base 601 to a PV generator and then from the PV generator to the environment.

According to some embodiments, disposing a first group of bypass mechanisms (e.g. D1-D3) on junction box base 601 and a second group of bypass mechanisms (e.g. D4) on junction box cover 602 (e.g. as in FIG. 6C) may both safety and thermal advantages. The first group of bypass mechanisms may ensure provision of a bypass path in case of a mismatch or underperforming PV generator or string, without risk of an improper manual mechanical connection of the bypass mechanisms. The second group of bypass mechanisms may reduce electrical loss and heat generation, and may be disposed on junction box cover 602 to dissipate heat in a manner which may be faster and more effective than dissipation of heat from bypass mechanisms mounted on junction box base 601.

According to some aspects, depending on the number of bypass mechanisms in junction box component 603, there may be one or more bypass mechanisms mounted on junction box base 601 and there may be one or more bypass mechanisms mounted on junction box cover 602. For example, two bypass mechanisms may be mounted on junction box base 601, and two bypass mechanisms may be mounted on junction box cover 602, while the bypass mechanisms are placed and configured to be coupled to their respected bus bars when junction box base 601 and junction box cover 602 are aligned and junction box 600 is closed.

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All optional and preferred features and modifications of the described embodiments and dependent claims are usable in all aspects of the invention taught herein. Furthermore, the individual features of the dependent claims, as well as all optional and preferred features and modifications of the described embodiments are combinable and interchangeable with one another. For example, cover 402 of FIG. 4 may include heat dissipation mechanisms such as heat dissipation mechanisms included in area 304 of FIG. 3C. As another example, junction box component 501 of FIG. 5A may include heat spreaders R5b as shown in FIG. 2E.

We claim:

1. A junction box comprising:

a cover,

a base comprising a first side and a second side, wherein the first side is configured to be mounted to a photovoltaic panel, the second side includes a plurality of connectors and circuitry, the plurality of connectors are adapted to electrically couple substrings of a photovoltaic generator to the circuitry, and the circuitry is configured to bypass a substring,

wherein the cover is configured to cover the second side of the base, and

wherein the circuitry includes:

a plurality of bus bars adapted to electrically couple each of the plurality of connectors to a separate bypass mechanism, wherein the plurality of bus bars are configured to function as multi-directional heat spreaders; and

a first output conductor and a second output conductor, each configured to output power harvested from the photovoltaic panel, wherein the first output conductor is coupled to a first bus bar and the second output conductor is coupled to a second bus bar; and

a bypass mechanism mounted on the cover and configured to electrically couple to the first bus bar and to the second bus bar of the base when the cover is placed over the base.

2. The junction box of claim 1 wherein, when the cover is placed over the base, the bypass mechanism mounted on the cover is coupled to the second bus bar with a conductive rod.

3. The junction box of claim 1, further comprising an additional bus bar configured to electrically couple to the bypass mechanism mounted on the cover when the cover is placed over the base.

4. The junction box of claim 1, wherein the bypass mechanism mounted on the cover is configured to connect the first bus bar and the second bus bar with a click mechanism.

5. The junction box of claim 1, wherein the cover further comprises output connectors configured to connect to other junction boxes or power devices.

6. The junction box of claim 1, wherein the cover further comprises a control unit and a power converter.

7. A method comprising:

mounting a junction box base on a photovoltaic generator; electrically coupling outputs of substrings of the photovoltaic generator to connectors and circuitry mounted in the junction box base, wherein the circuitry comprises a plurality of bus bars and a plurality of bypass mechanisms;

electrically coupling a first output conductor to a first bus bar and a second output conductor to a second bus bar; covering the junction box base with a junction box cover; and

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electrically coupling a bypass mechanism mounted to the junction box cover with the first bus bar and the second bus bar of the circuitry mounted to the junction box base.

8. The method of claim 7, further comprising thermally coupling the circuitry mounted in the junction box base to the junction box cover.

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